Models on the Move: Migration and Imperialism

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Abstract

We introduce 'model migration' as a species of cross-disciplinary knowledge transfer whereby the representational function of a model is radically changed to allow application to a new disciplinary context. Controversies and confusions that often derive from this phenomenon will be illustrated in the context of econophysics and phylogeographic linguistics. Migration can be usefully contrasted with concept of 'imperialism', that has been influentially discussed in the context of geographical economics. In particular, imperialism, unlike migration, relies upon extension of the original model via an expansion of the domain of phenomena it is taken to adequately described. The success of imperialism thus requires expansion of the justificatory sanctioning of the original idealising assumptions to a new disciplinary context. Contrastingly, successful migration involves the radical representational re-interpretation of the original model, rather than its extension. Migration thus requires 're-sanctioning' of new 'counterpart idealisations' to allow application to an entirely different class of phenomena. Whereas legitimate scientific imperialism should be based on the pursuit of some form of ontological unification, no such requirement is need to legitimate the practice of model migration. The distinction between migration and imperialism will thus be shown to have significant normative as well as descriptive value.

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1 Introduction

An interesting and controversial instance of scientific models moving from one discipline to another is the use of statistical physics models in the context of the economics of wealth distributions. *Kinetic exchange* models, originally designed in the context of statistical mechanics, are used to recover certain 'stylised facts' about the distribution of wealth. Models originally interpreted in terms of exchanges of kinetic energy between molecules in a gas are reinterpreted in terms of monetary exchanges in an economy.[1] Similarly controversial is the use of Bayesian phylogeographic models in historical linguistics. Powerful computational techniques designed to investigate the origin of virus outbreaks based upon geographic and molecular sequence data are applied to make inferences about the historical spread of languages.[2] Such examples illustrate a phenomenon, which could be called 'model migration', whereby models move from one discipline to another via a radical change in their representational function.[3] Model migration can be contrasted with what Mäki and Marchionni (2011, 2011), among others, have called 'imperialism'. The particular focus of Mäki and Marchionni is on economics imperialism (although various other cases have been discussed in the literature) and good illustrative examples of the phenomenon can be found in geographical economics. Imperialism involves an expansion of the domain of application of models in the 'imperialistic' discipline to include target systems traditionally described by the models of a 'colonised' discipline.

In this paper, we argue that migration and imperialism are distinct kinds of cross-disciplinary knowledge transfer between which it is important to distinguish. Successful imperialism relies upon justificatory arguments for the legitimacy of essentially the same

[1] See Chakrabarti et al. (2013) for a comprehensive introduction to 'kinetic exchange' models of wealth distribution. Criticism from the perspective of traditional economics is most piquantly found in Gallegati et al. (2006). For extensive philosophical discussion see Thébault et al. (2016).

[2] The particular example we have in mind is application of the techniques of Lemey et al. (2009, 2010) to the problem of the location of the homeland Indo-European languages by Bouckaert et al. (2012, 2013). For earlier work along related lines see (Gray and Jordan 2000) and the articles in the collection Forster and Renfrew (2006). See Levinson and Gray (2012) and Gong et al. (2014) for review articles. Analysis of potential problems with such approaches can be found in Heggarty (2006, 2014), Mallory (2013). An interesting related controversy is discussed in the exchange between Atkinson (2011, 2012) and critics (Cysouw et al. 2012; Wang et al. 2012; Van Tuyl and Pereltsvaig 2012) regarding the use of a model of phonemic diversity to argue for an 'out of Africa' account of modern languages.

[3] We should note that, although we do not subscribe to many aspects of his story regarding models in general, our concept of migration is similar in some respects to Weisberg's notion of 'construal change' in the context of the same 'model structure' being borrowed from one 'modelling domain' to another – see in particular Weisberg (2012, p.75-79)). A further related, but much more general, notion found in the literature is the idea of 'computational templates' that travel across disciplines and which can receive domain-specific modifications (Humphreys 2004). See Marchionni (2013) for an excellent discussion of computational templates in the context of network science. See §4.1 for dicussions of the relationship between model migration and the precisification of Humphreys' idea as 'model templates' due to Knuuttila and Loettgers (2014).

idealisation, being extended to a wider context. The scope of the model's 'sanctioning' has been expanded; we could say that the 'certificate of permissible applications' has been extended to cover a wider range of circumstances. On the other hand, because there has been a reinterpretation of the model's representational function, successful migration relies upon potentially very different 'counterpart idealisations' being justified in the new context. The model must be 're-sanctioned' in the sense that a new certificate of permissible applications must be provided. Although superficially similar, migration and imperialism are substantively different in terms the norms needed for their successful operation. Misconstrual of a case of migration as a case of imperialism will understandably lead to practitioners 'talking past each other'. Our binary focus upon migration and imperialism is driven by the high stakes resting upon the distinction together with the tendency of scientific communities, both in our cases studies and more generally, to conflate the two. Our core proposal is that by evaluating cases of model migration in terms of the concept of re-sanctioning, philosophers of science will be well placed to formulate relevant and useful norms for this important species of cross-disciplinary knowledge transfer. In particular, engaged critical analysis of idealisations involved in migrant models requires awareness of modelling practices from both the old and new context. Successful model migration calls for concerted cross-disciplinary efforts in a manner unlike more traditional knowledge transfers that operate within one discipline or between adjacent disciplines. For this reason we believe that migration, and the accompanying re-sanctioning process, call for a specific cross-disciplinary normative framework. The principal aim of this paper is to provide such a framework.

In the following section we present our two cases studies of model migration, first considered separately, in §2.1 and §2.2, and then side-by-side, in §2.3. In the next section, we first, in §3.1, offer a short overview of an important case study of imperialism, geographical economics as discussed by Mäki and Marchionni (2011). and then, in §3.2, present a summary of the relevant norms of imperialism coming from that discussion. Next, in §3.3, we consider the contrast between migration and imperialism in detail. A different comparison is between notions of 'analogue modelling' that appear in the philosophy of science literature and our notion of model migration. We will consider the relationship between model migration and analogue models in §4.1, before developing an framework for analysing and assessing the general phenomena of model migration in §4.2 and, finally, providing our normative framework in §4.3.

2 Migration: Case Studies

2.1 Econophysics of Wealth Distributions

There is a long list of precedents for models 'migrating' from physics to economics. A particularly strong connection is between the models of statistical physics and those of financial economics.[4] But econophysics is something different. The term econophysics, describes the '...attempts of a number of physicists to model financial and economic systems using paradigms and tools borrowed from theoretical and statistical physics' (Stanley and Mantegna 2000, p. 355). What is particularly distinctive about econophysics, as opposed to the previous waves of knowledge transfers along the same route, is

[4]See Mirowski (1992) for a historical review of relationship between physics and economics. See Weatherall (2013) for a popular introduction to the 'Physics of Wall street'.

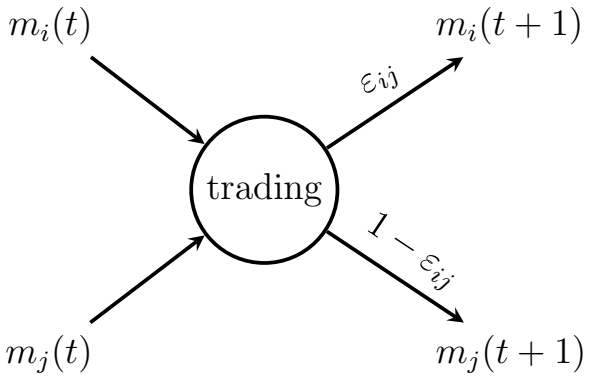

Figure 1: The DY exchange dynamics (after Chakrabarti et al. [2013], Figure 4.1, p.56)

the degree to which its practice, norms and institutions have remained anchored within physical science, even as the targets of study have radically changed. That is, econophysicists typically still work in physics departments and publish in physics journals (Gingras and Schinckus 2012). Philosophical work on the methodological foundations of econophysics is fairly limited with a small literature, focusing on financial econophysics, due to Kuhlmann (2006, 2014), Rickles (2007, 2008), Casini (2014) and Jhun et al. (2017). In a recent paper, Thébault et al. (2016) provided a philosophical analysis of the example of kinetic exchange models of wealth distributions. Here we will briefly consider the key details of the most basic 'kinetic exchange' model of wealth – the 'DY' model of Drăgulescu and Yakovenko (2000) – in order to illustrate the idea of model migration. Most, although perhaps not all, of the modelling that goes on in econophysics could be expected to be described well within the conceptual framework of migration.

Consider the most basic kinetic exchange model of molecules in a gas – that of Boltzmann (1872).[5] We assume a large but finite number of molecules that undergo binary dynamical interactions according to a scattering process between ideal hard spheres. The molecules exchange translational kinetic energy via this scattering and it can be shown analytically that after some time the velocity distribution will relax to the Maxwell-Boltzmann exponential form that is found in experiments on real (monoatomic) gasses. The DY model applies essentially the same line of reasoning to a population of economic agents, exchanging money via a random trading process. At any given time t an agent i has associated with them a single property, their money $m_i(t)$. For two chosen agents, the initial pre-interaction state can be characterised completely in terms of two numbers: $m_i(t)$ which is the wealth of agent i at time t; and $m_j(t)$ which is the wealth of agent j at time t. In an agent-agent 'collision' all the money of the two agents is pooled, and then a random fraction is given to one, and the rest to the other. This simple exchange mechanism is shown in Figure 1. A simple analytical argument via maximum entropy reasoning (Banerjee and Yakovenko 2010) then implies that the stable form of the distribution will again be of the Maxwell-Boltzmann exponential form, only with the average money per agent playing the role of temperature. Impressively this model captures the 'stylised fact' that the bulk (i.e. bottom 80-90%) of real wealth distributions is of exponential form.[6]

The DY kinetic exchange model of wealth functions as an exemplar of 'model migration' since it resulted from a radical modification of the representational function of

[5]See Emch and Liu (2002), Uffink (2014) for detailed discussion and analysis.

[6]Extending the model to include a 'savings propensity' allows one to recover the 'power-law tail' distributions also. See Chakrabarti et al. (2013)

the terms of the Boltzmann kinetic exchange model of gases. The structural form of the two models is very similar (although not identical), and yet the objects represented are vastly different: molecules in one case, economic agents in the other. Importantly, such a structural relationship between models is necessary but not sufficient for a case of model migration. The concept of model migration involves reference to real scientific practice within the process of re-interpretation. Migration is, properly speaking, something scientists do with their models in practice, rather than an abstract conceptual relation. That is, two models may be structurally related but have entirely separate origins. In such circumstances neither model would have resulted from 'migration' and the analysis of their structural similarity would be an interesting philosophical problem, entirely separate from our current concerns. Model migration is historically contingent, and intimately tied to the relevant 'context of justification' of the model at the point it is first applied to a new domain. We shall return to this point later.

2.2 Bayesian Phylogeographic Linguistics

Our second example of model migration also features a model moving from a natural science context to a social science context. However, this time the relevant model is from the life sciences, in particular evolutionary biology, and the new modelling context is the human sciences, in particular historical linguistics. Like with the econophysics example, we can reasonably take our example to illustrate a wider class of cross-disciplinary migration patterns. In particular, the movement of models from evolutionary biology to various social science contexts.

A phylogenetic tree represents the genealogical relationship among species in terms of a branching structure. Species with more genetic similarity are understood to have had more recent common ancestors and are therefore represented as closer together on the tree: they are situated on branches with a common root node. Contemporary biology makes use of a variety of methods to infer phylogenetic trees based upon observed genetic data. In *Bayesian phylogenetics*, trees are reconstructed using molecular sequence data together with computational techniques, and rules of inductive inference.[7] The basic idea is to model evolution as a stochastic molecular process and use a computer to reconstruct all the possible historical relationships between species – i.e. the trees – that are consistent with the observed genetic data – i.e. the branch tips. Bayesian inductive inference can then be used to calculate a posterior probability for any given phylogenetic tree based upon the observed data. Thus, using Bayesian phylogenetics we can infer what the most likely historical relationships are between species based upon the genetic diversity we observe now.

A more full explanation runs as follows. A phylogenetic model consists of a stochastic model of genetic evolution via nucleotide substitution and a tree with branch lengths representing the number of substitutions expected to occur. Nucleotides are organic molecules that are the sub-units of DNA strands and mutation of DNA is typically via specific channels for change in the chemical structure of nucleotides. Hence, key features of genetic evolution can be well described in terms of models of nucleotide substitution. We feed molecular sequence data into the model and get out posterior probabilities for different possible phylogenetic trees. Explicitly, the posterior probability for phylogenetic

[7] See Felsenstein (2004) for a general introduction, Yang and Rannala (2012) for an accessible scientific review article, and Autzen (2016) for discussion of a fascinating associated philosophical puzzle.

tree, τ_i is given by:

$$f(\tau_i|\boldsymbol{X}) = \frac{f(\boldsymbol{X}|\tau_i)f(\tau_i)}{\sum_{j=i}^{B(s)} f(\boldsymbol{X}|\tau_j)f(\tau_j)} \tag{1}$$

where $\boldsymbol{X}$ is observed matrix of aligned DNA sequences; $f(\boldsymbol{X}|\tau_i)$ is the likelihood; $f(\tau_i)$ is the (assumed to be uninformative) prior; and $B(s)$ is the number of possible trees for s species. In practice a simple analytic treatment is usually not possible. One problem is that the likelihood will usually depend upon several unknown parameters. The method of maximum likelihood estimates these parameters. Moreover, the posterior probability cannot typically be be calculated analytically. The Markov Chain Monte Carlo (MCMC) method is thus used to sample phylogenies according to their posterior probabilities.

Bayesian phylogeography involves integrated models based on *both* molecular sequence data and spatial location data. The idea is to model the spatial and temporal dynamics of gene flow, such that posterior probabilities can be estimated for the location of the root of the relevant phylogenetic tree in both space and time. To do this scientists make use of Continuous Time Markov Chain (CTMC) models for both genetic evolution and spatial dispersion of genes. In the model that is the focus of our analysis, Lemey et al. (2009, 2010) designed a Bayesian phylogeographic model to investigate the origin of virus outbreaks based upon geographic and molecular sequence data on Avian influenza A-H5NA and Rabies in Africa. The potential practical importance of such techniques is not difficult to see. Bayesian phylogeographic techniques provide a tool for us to make inferences about historical patterns of virus outbreaks based upon its current genetic diversity and spatial distribution. Besides the application of these models in evolutionary biology, there are natural extensions to closely related areas of the life sciences such as biogeography (Ronquist and Sanmartín 2011). However, although undoubtedly important and interesting such 'intra-disciplinary' knowledge transfers are not the subject of our current analysis. Rather, what is particularly remarkable about Bayesian phylogeographic model of Lemey et al. (2009, 2010) is that it found an almost immediate re-application in an entirely different context: historical linguistics.

Historical linguistics is the scientific study of written and spoken languages and their change through time. As such it crosses between formal linguistics, philology, archaeology and anthropology. One of the most fascinating and long standing questions in historical linguistics is the origin of the Indo-European language family. The family contains a vast array of contemporary languages – from Hindi to Irish – and half the people in the world speak a language from this group. The existence of such familial relationships between languages spoken in very distant parts of the world has been accepted since the nineteenth century. The term 'Indo-European languages' was coined by Thomas Young in 1813 and the concept of the family stems from the long observed similarities between Sanskrit, Latin and Ancient Greek. These similarities were famously described in 1786 by Sir William Jones, an English Judge serving in the Indian high court. He remarked:[8]

> The Sanskrit language, whatever be its antiquity, is of a wonderful structure: more perfect than the Greek, more copious than the Latin, and more exquisitely refined than either, yet bearing to both of them a stronger affinity, both in the roots of verbs and in the forms of grammar, than could possibly have been produced by accident; so strong indeed, that no philologer could

[8]This quote is the rendering of Anthony (2010, p.7) and historical details on the Indo-European question are taken from both this account and that of Renfrew (1987).

> examine them all three, without believing them to have sprung from some common source, which, perhaps, no longer exists.

The precise geographical origin (or 'homeland') of the last common ancestor language of the entire Indo-European family is a matter of ongoing dispute. As is the related question of the method and date of dispersal. The two major competing hypotheses are: i) an origin on the Pontic-Caspian Steppe, with dispersal via the domestication of the horse beginning around six thousand years ago (Gimbutas 1970; Mallory 1989; Anthony 2010) ; or ii) an origin in central eastern Anatolia, with dispersal via the spread of farming beginning around nine thousand years ago (Renfrew 1987).[9] In a controversial and much reported study, Bouckaert et al. (2012, 2013) adapted the Bayesian phylogenetic model of Lemey et al. (2009, 2010) in order to evaluate the two competing hypotheses probabilistically. They used as their input data basic vocabulary terms and geographic range assignments for 103 ancient and contemporary Indo-European languages. Language evolution was modelled via a CTMC as the gain and loss of homologous words – i.e. cognates like *night, nuit, Nacht* – through time. The model was tested on the problem of reconstructing the romance language family, where it gave the (rather reassuring) location of the relevant 'homeland' as Rome. When applied to the Indo-European data, the model gave very strong probabilistic support for the Anatolian hypothesis over all other possible homelands, including the Pontic-Caspian Steppe.

We take Bayesian phylogeographic linguistics in general, and the model of Bouckaert et al. (2012, 2013) in particular, to provide a further vivid exemplification of our notion of model migration. As with the DY model, we have a case of scientists performing radical reinterpretation of the representational function of the terms of a model: from genes to languages, and from nucleotide substitutions to gain and loss of homologous words. And as in the econophysics case, there is a structural continuity between the models that persists despite this radical semantic shift. As well as illustrating the positive and exciting aspects of migration, our two examples have been chosen to exemplify the general features of the associated controversies. In the next section we will consider the controversies specific to our two case studies side-by-side.

2.3 Interdisciplinary Indiscipline?

In many key respects the examples discussed in the previous two sections stand as exemplars for the vast array of relevantly similar 'migrations' of models from one discipline to another that have gone on over the last century.[10] Our two examples are, however, particularly controversial: in each case the 'migrant models' have been attacked as in principle inappropriate to the new context. Consider the following:

> There is a general (and understandable) tendency on the part of econophysicists to develop theoretical models, which are based on the principles of statistical physics... [in general] models constructed on these principles ignore absolutely fundamental features of economic reality. Any congruence obtained with the data by such models is therefore spurious.

[9] Here we are following the description of Heggarty (2014).

[10] This phenomenon has not entirely escaped the philosophical literature, which contains particularly noteworthy contributions concerning evolutionary biology models migrating into economics (Rice and Smart 2011), game theory models into biology (Grüne-Yanoff 2011), spin lattices models into neuroscience (Knuuttila and Loettgers 2014) and ecology models into economics (Weisberg 2012, p.75-79).

Gallegati et al. (2006, p.4)

> ...The Indo-European case remains symptomatic of how debates on prehistory, and on novel methodologies for illuminating it, often fracture along a fault-line between the natural and social sciences, and between qualitative and quantitative analyses...divergence (if not change) in our languages is primarily hostage to, and shaped by, the relationships, contacts and fates of the human societies and populations that speak them – rather than by culture-blind, invariant 'laws of nature'. Many historical linguists thus share with many historians, archaeologists and anthropologists a reticence to see their object of study tracked and modelled in quantitative and especially evolutionary frameworks.

(Heggarty 2014, p.568-9)

In each case closer inspection reveals the general species of problem isolated by the critics: key idealisations inherited from the original modelling context are inappropriate to the new context. Practitioners in the new context can take these *counterpart idealisations* to be illegitimate, and they are one source of scepticism about the migrating model. What should philosophers of science make of such inter-disciplinary disputes? Let us return to our two examples and consider one pair of counterpart idealisations in each case.

In the case of the Boltzmann gas model one crucial idealisation is that interactions between gas molecules are binary. This assumption is crucial not just to Boltzmann's model but to almost all treatments of such systems up to the present day. In the introduction to one of the standard textbooks on the topic we find the authors noting that 'the legitimate neglect of all but binary encounters in a gas is one of the important simplifications that have enabled the theory of gases to attain its present high development' (Chapman and Cowling 1991, p.3) What *legitimates* the binary collision idealisation in the gas case? A relatively simple answer is found in terms of the density regime of the gases to which the model is applied. In a very dilute gas we will find on average a vanishingly small number of collisions between molecules on reasonable timescales. And in a very dense gas we will find a non-negligible number of collisions involving three or more molecules. Between these two regimes there is a 'Goldilocks zone' where two-molecule collisions dominate. As a matter of contingent fact, this is the regime we are interested in, given terrestrial temperatures, pressures and timescales. Thus, for the target systems of interest – gases on earth – the binary interaction idealisation of the Boltzmann model can be justified on the grounds that it is a valid approximation to 'reality'. The gas model can thus be 'sanctioned' in that it can be provided with a 'certificate' specifying its permissible applications.[11] Clearly, however, these grounds for justifying the binary interaction idealisation and sanctioning the gas model, are irrelevant to the legitimacy of the counterpart idealisation of binary agential interactions and thus the sanctioning of the econophysics model. We cannot justify binary interactions in the economic case by appeal to contingent facts about some analogue of the 'density regime' of agents! So, prima facie, there are reasonable grounds for economists to be concerned about the legitimacy of the idealisations involved in kinetic exchange models of wealth.[12]

[11] Here we are adapting the term from Winsberg (1999).

[12] See Thébault et al. (2016) for a detailed discussion of the various idealisations involved in the DY model together with analysis of their legitimacy.

Phylogenetic approaches in evolutionary biology, including the phylogeographic models used by Lemey et al. (2009, 2010), are built upon component models of DNA sequence evolution in terms of a stochastic process of nucleotide substitution. In this case, the particular model is called HKY85, after a model used by Hasegawa, Kishino, and Yano (1985) within which one distinguishes between amplitude of 'transition' between nucleotides of the same molecular structure and 'transversions' between nucleotides with different molecular structure. Clearly much idealisation is involved when the complicated bio-chemical processes behind the mutation of organic molecules is represented via a stochastic process of substitution. And clearly the bio-chemical justification for the use of a model of genetic evolution as nucleotide substitution is, again, irrelevant to the justification for the use of a model of linguistic evolution as gain and loss of cognates, whether or not these models are formalised in the same way via CTMCs. In fact, Heggarty (2014) notes that language phylogenies are more reliably established from phonology (sound) and morphology (word structure) rather than just homology: a particular problem is the existence of 'borrowings' (like the French words in English) that could confound a homology based phylogeny – see Heggarty (2006) and Mallory (2013) and for further critical comments.

Thus we again see that there are prima facie plausible reasons for doubting the validity of results produced from migrant models. Practitioners of traditional approaches are not simply acting as reactionaries (or inter-disciplinary xenophobes!); at least on a general level, their reasons for worrying are well justified.[13] How should practitioners of migratory modelling respond to these criticism? Are there general morals about the process justifying counterpart idealisations that we can draw? We will return to these question in the final section of this paper. Before then, by way of offering a contrast class, we will consider a very different, and also controversial, movement of models between disciplines, that have been categorised in the literature under the name of 'imperialism'.

3 Imperialism

3.1 Geographical Economics

Geographical economists are interested in the geographical or spatial distribution of various kinds of entities at various scales: 'industry clusters, core-periphery patterns among countries and regions, cities and systems of cities, patterns of international trade and specialization, and the causes of economic growth and development.' (Mäki and Marchionni (2011, p.192)) Geographical Economics (GeoEcon) explains this variety of phenomena by considering the behaviour of economic actors optimising given constraints of wage competition and transportation costs. Essentially, GeoEcon treats the decision of where to base your business as a trade-off between two factors: transportation costs and increased competition. Locating near your consumers reduces transportation costs. However, locating near your consumers likely means locating near your competitors as well. Such increased competition will drive up your costs and drive down your prices. Various kinds of distribution patterns of industries are then taken to be explained by the interplay between these factors. When transportation costs are high, the advantage of being near your customers likely outweighs the increased costs due to extra competition and thus

[13]It is here, perhaps, that our politically inspired terminology becomes most misleading. Within mainstream political discourse at least, well reasoned and justified criticism of migration is invariably conspicuous by its absence. See Dummett (2001) for an excellent discussion.

'agglomeration' is more likely. Contrastingly, when transportation costs are low, moving out of town is not as much of a disadvantage, and thus the balance is tipped in favour of locating away from your competitors to reduce competition.

Consider a simple economy where there are two types of industry – farming and manufacturing – and two geographical regions – North and South.[14] Farmers are tied to their fields, so their locations are fixed, but the manufacturers can choose where to locate their factories. The manufacturers sell to farmers and to other manufacturers. There are costs for transporting goods to the region the factory is not located in. Thus, other things being equal, the manufacturers prefer to locate in the region where they sell more goods: this reduces their transport costs and thus increases their profits. One starting point for the GeoEcon model is that, other things being equal, the decision of where to locate depends on transportation costs. But other things are not equal: if a company locates its factory in a region where there are already many factories, there is competition for workers, which drives up wages, which drives up costs, which drive down profits. Locating where there is little competition for workers – and thus where wages are lower – might compensate for higher transportation costs. This is the other main piece of the puzzle: the decision of where to locate depends on wage competition. Both drivers of the model – transportation costs and wage competition – depend on the location of the other economic actors. When it is better for the firm to locate near other factories to reduce transportation costs and to accept higher wage bills as a result, then the firms will agglomerate. The demand for jobs will drive migration towards the agglomeration (which, incidentally drives down wages through competition). This is the putative explanation provided by Geographical Economics for the genesis of cities. People tend to cluster when transportation costs give them an incentive to locate near their suppliers and customers: when increased competition (due to nearby competitors) is outweighed by lower transportation costs.

Geographical Economics aims to offer an explanation of why people cluster in cities in terms of a *purely economic* decision. In doing so it treats humans making decisions as to where to live as highly idealised economic agents. The decision making process is one that consists in the constrained optimisation of a very sparse set of considerations. Despite its attractive simplicity, this GeoEcon explanation clearly fails to account for various sociological and socio-psychological reasons that influence people's choices to live close together rather than spread evenly across the countryside. It is for this reason that GeoEcon is cast as an unwarranted colonisation of a long standing and central topic in the human sciences. In particular, GeoEcon ignores a number of important explanatory factors studied by anthropologists, human geographers, sociologists and even network scientists.[15] GeoEcon is imperialistic because it treats those agents who decide where to establish their business as agents of the same kind as those studied in other areas of economics. GeoEcon effects an increase in the scope of economics, by explaining a class of phenomena that were not originally thought of as purely economic phenomena, using the theories and techniques of economics only.

[14] Our presentation follows Brakman, Garretsen, and van Marrewijk (2009), chapter 3

[15] The list of relevant literature is vast. See for example (Weber 1958; Carter and Donald 1993; Portugali 2012).

3.2 Norms of Imperialism

Mäki and Marchionni (2009, 2011, 2011) see GeoEcon as part of a general push to explain as much as possible from an economic perspective. This idea of the ever-increasing scope of economic methodology has been called 'economics imperialism'. In these papers, and elsewhere (Mäki 2013), Mäki adopts a nuanced view of when economics imperialism (and other science imperialisms) can be beneficial.[16] Others have been more critical of imperialism. John Dupré, in particular, has been critical of (among other things) rational choice theory as a science of human nature. According to Dupré it is illegitimate to treat humans as always behaving like economic agents, and the drive to do so is a pernicious form of imperialism.

> ...typical imperialists do not merely establish embassies in foreign countries and offer advice to indigenous populations. And similarly, economic imperialists do not merely export a few tentative hypotheses into the fields they invade, but introduce an entire methodology and one that is in many cases almost entirely inappropriate. Here I mean by 'methodology' two things: first, a set of core assumptions about how to conceive of the phenomenon under investigation, in this case human behaviour; and second, a methodology in the strict sense of a style of scientific argument.
>
> (Dupré 2001, p.128)

The analogy to political imperialism is made even more explicit by Clarke and Walsh:

> Colonised disciplines accept and attempt to apply the methodologies of the invading discipline on the grounds that these have proved to be fruitful elsewhere. In doing so they fail to appreciate that such methodologies bring with them a way of approaching their subject matter that sheds light on some aspects of the subject of study but obscures others. Valuable 'indigenous knowledge' that might otherwise be gained, may be overlooked and valuable indigenous knowledge that has already been gained may be lost, when a successful instance of scientific colonisation takes place, or so the opponent of scientific imperialism can argue.
>
> (Clarke and Walsh 2009, p.202)

In contrast, to such critical appraisals of imperialism, some – most notably Lazear (2000) – have been happy to accept that a tendency towards imperialism can be a successful and worthwhile feature of a discipline. In particular, Lazear argues that the incursions into neighbouring disciplines that economists have made in the past half century have had predominantly positive effects on those areas of knowledge.

Although evocative and in many ways insightful, ultimately the analogy between political and disciplinary imperialism may serve to obfuscate as much as illuminate. In particular, it does not seem reasonable to cast disciplinary imperialism as in principle illegitimate, but rather to see it as a phenomenon that can be practiced to to the mutual benefit of all, given appropriate norms.[17] Plausible examples of such norms are provided

[16] See also Fumagalli (2017).

[17] For this reason it might be argued the terminology of 'imperialism' is unhelpful. Although Mäki and Marchionni may not have had such an intention, the word imperialism has an unavoidable pejorative connotation in modern English, not least through the deep political connections between political imperialism and ethno-national chauvinism.

by Mäki (2013) in terms of constraints on the pursuit of explanatory unification across disciplinary boundaries. We will discuss three of Mäki's four constraints here as they will prove important in our contrastive analysis in the context of the norms of migration discussed in §4.3.[18]

Mäki's first constraint relates to ontological unification of the diverse phenomena found in the imperialistic and colonised discipline.

> The pursuit of unification in its ontological mode is a legitimate process of discovery of the extent to which there is unity in the world itself: the extent to which parts of the world are made of similar components, governed by similar laws, or generated by similar causal mechanisms, and so on...the first constraint on scientific imperialism is that it should be based on the pursuit of ontological unification (Mäki 2013, p.336)

The contrast between Mäki's first norm of imperialism, regarding ontological unification, and what we present as the first norm of migration (§4.3), regarding re-sanctioning, will prove highly instructive.

Mäki's second constraint for imperialism is essentially a norm of epistemic humility. The basic, and very reasonable, idea is that 'epistemic caution is advisable when accepting and rejecting theories and explanations both on the home grounds of a discipline and in far away territories' (p.336) which implies, more prescriptively, that '[a]ny imperialistic claims about the cross-disciplinary unity of phenomena must be accompanied by explicitly stated careful provisos rather than hidden uncertainties' (p.337). The final constraint on imperialism (Mäki's fourth) that is relevant to our comparison, then relates to institutional practice:

> The pursuit of cross-disciplinary unification should proceed under the guidance of the rules and regulations of appropriately virtuous scientific practice. Imperialism that proceeds by engaging in open debate and by spelling out and defending its presuppositional posits is more acceptable than imperialism that succeeds merely or mostly by relying on the academic and non-academic standing of the imperialistic discipline.

In §4.3 we will see that the norms of imperialism implicit in Mäki's epistemic and institutional constraints have natural parallels in the norms of migration.

3.3 Imperialism and Migration

There are some obvious similarities between what we called 'model migration' and 'scientific imperialism'. Both essentially involve interdisciplinary transfer of knowledge: some aspect of a theory in one domain – the original disciplinary context – is brought to bear on scientific problems in another area of inquiry – the new disciplinary context. Both kinds of interdisciplinary knowledge transfer are often resented by practitioners in the new disciplinary context, and often for similar reasons: work of this kind is not sufficiently responsive to or respectful of the 'indigenous knowledge' of the new disciplinary context. This notwithstanding, there are important contrasts between migration and imperialism

[18]Mäki's third constraint – his 'axiological' constraint – is basically that the success of a scientific endeavour is judged in terms of its importance; and importance is relative to human needs and values. This seems to be true of all scientific endeavours, rather than just those that fall under the scope of imperialsim.

that should not be overlooked. In particular, although migration and imperialism both involve models 'moving' from one discipline to another discipline, imperialism is unlike migration since it can be adequately understood in terms of an increase in scope of the domain of validity of the original model.

In discussing GeoEcon, Mäki and Marchionni emphasise that GeoEcon represents a kind of 'explanatory unification' whereby phenomena that were not previously explained in economic terms come to be explained in the same way as other economic explananda. Here it is useful to differentiate between derivational and ontological unification: the former involves several phenomena being explained by the same kind of mathematical model, the latter involves several phenomena being explained by the same kind of underlying causal structure. According to Mäki and Marchionni, successful instances of imperialism often involve both: they are 'motivated by ontology, facilitated by mathematics' (Mäki and Marchionni 2009, p.10). In the GeoEcon example, whereas the mathematics of constrained optimisation provides the derivational unification of spatial distribution of companies with other economic phenomena, the idea that companies act like constrained optimisers provides the ontological unification. Let us put to one side these notions of 'ontological unification' and 'derivational unification' and also questions of explanation.[19] For our purposes the important point is that on the Mäki and Marchionni account, successful imperialism relies upon exploiting an ontology that is shared (or at least similar) between the new and old disciplinary contexts. Contrastingly, migration, unlike imperialism, does not rely upon a shared ontology in any significant sense. Econophysicists do not think that agents in an economy and gas molecules have ontological features in common. Nor do scientists appealing to Bayesian phylogenetic linguistics think that words and genes share an ontology. In each case the claim is only that very different systems can be effectively modelled via structurally similar equations. The important distinction for our purposes is that imperialism involves assuming that the same kind of thing is happening in two apparently distinct domains *because of some similarity in the underlying ontology*: the agglomeration of people into cities is driven by purely economic motives and thus economic theory applies. Migration, on the other hand, makes no assumption about ontology, it just involves the recognition that an abstract model can be fruitfully applied in another sphere.

A small detour into counterfactual history of science will help illustrate the distinction between migration and imperialism further. Fresnel's wave theory of light postulated a luminiferous ether: a fluid through which light waves travel as surface waves travel through water or sound wave travel through air. This was very natural since the concept of a wave was, at that time, necessarily connected to the idea of a disturbance in a medium. If light travelling through space was to be a wave, then there must be an as yet undetected medium that occupied all of space. The real history of this episode could be used to illustrate (intra-disciplinary) imperialism. Fresnel took a model of the dynamics of waves in a conventional fluid medium, and applied it in a new domain, a domain he thought was ontologically similar: in both cases we are dealing with waves moving through a fluid. In fact, by modern scientific lights, there is no such thing as the luminiferous ether. Thus, counterfactually, Fresnel's wave theory of light *could have* been arrived at as a case of model migration. In our alternative scenario Fresnel's model is derived without belief in an ontological similarity between light waves and conventional

[19]Neither explanation nor unification are our focus here. Rather our aim is to emphasise the difference between migration and imperialism and we can do this *without* considering vexed questions of explanation or relying upon Mäki and Marchionni's two kinds of unification.

fluid waves but rather via a radical reinterpretation of the intended domain of the existent fluid wave models. Whether the norms of imperialism or migration ought to apply in this case depends on what *Fresnel thought he was doing and how he justified it.*

For the purposes of our present analysis, we are interested in the methodology of science as done by scientists, so what is important is not whether there is genuinely a shared ontology between two uses of the same model. Rather, what matters to us is whether or not the modellers in question believe there is a shared ontology.[20] Fresnel, if he thought he was simply extending the fluid mechanical theory of waves to a new kind of fluid, should be considered as engaging in imperialism and be governed by its norms. If instead Fresnel had not been thinking in terms of a fluid ether, but was rather using a model coming from fluid mechanics to explain what he took to be the *sui generis* phenomena of light, then he should be judged by the standards of the norms of model migration. The question of whether or not there 'really is' a luminiferous ether is simply beside the point in establishing whether or not Fresnel was justified in adopting his chosen modelling strategy. In this sense we are internalist about the justification of modelling practice.

In a similar vein, consider Hotelling's model of the location of firms and its application to the political spectrum (Hotelling 1929). Consider a beach with people evenly distributed along it. Where should an ice cream stand locate itself? Imagine that there are two ice cream stands located one third and two thirds of the way along the beach. Each beachgoer wants to travel the minimum distance to buy ice cream: the differences between the stocks of the two vans doesn't matter to the consumers, only their location. Each van gets about half the beachgoers coming to their van. If a van were to locate itself dead centre, it would get more than half the custom: all the people from one side, and half of the people between that van and the other van. So each van has an incentive to move towards the middle. The same model has been used to explain why politicians have an incentive to move towards the middle of the 'political spectrum'. Is this imperialism or model migration? The first thing to say is that a one-dimensional beach is an abstract representation of a physical system, while a one-dimensional political spectrum is an abstract representation of something that is, itself pretty abstract. So are the two models ontologically similar or not? This is an interesting question but not the relevant one to our task at hand. Rather, the question is did they modelling practitioners who first extended the model from the first context to the second rely upon ontological similarities to justify counter-part idealisations within the new modelling context? If yes, then an analysis based upon imperialism would be more appropriate. If no, then ideas from model migration (or perhaps analogue modelling see §4.1) would be more appropriate.[21]

The contrast between imperialism and migration must be understood as between two different things that scientists do with their models in practice, rather than between two distinct abstract ahistorical conceptual relations.

[20]We accept that how much ontological similarity the scientists themselves see might be vague, or a matter of degree in practice.

[21]In actual fact, Hotelling himself pointed out the political application of his model from the outset – thus neither framework is entirely appropriate.

4 Migration: Morals

4.1 Migration and Analogy

The goal of the paper thus far has been to explicate our notion of model migration by way of two case studies together with the comparison with imperialism. The last section has, we hope, established that migration and imperialism are different types of knowledge transfers, with different accompanying methodological issues. In this section we will make the further comparison between model migration and 'analogue models'. Our aim will be to highlight important differences between migration and analogy, whilst also noting useful connections that can be drawn between our notion of migration and the existent analogue models literature.

Analogical inferences play an important role in science and the topic has been fairly extensively discussed in a literature that features work by Keynes (1921), Hesse (1964, 1966), Bailer-Jones (2009) and Bartha (2010, 2013). A focus of much work in the topic is upon the heuristic role that analogies to another area of science can play in the construction of models. In this sense analogical connections are typically forward looking statement regarding potential heuristics for model development: they provide 'cognitive strategies for creative discovery' (Bailer-Jones 2009, p.56). Often scientists use the analogy between two systems as a heuristic to construct a model of one, partially based upon the model of the other.

An important distinction, due to Hesse (1964), is between 'material analogies' due to relevant similarity of properties between two systems, and 'formal analogies' when two systems are both 'interpretations of the same formal calculus' (Frigg and Hartmann 2012). Crucially, in both cases, the analogical relationship holds between the target systems in question, rather than models which are understood to represent these systems in some restricted domain of validity. Our notion of model migration does not in principle depend upon any analogy (material or formal) between target systems existing. It is a phenomenon built upon historical relationships at the level of the models, rather than analogical relationships at the level of target systems. Model migration can and does operate under conditions of extremely weak or non-existent analogy between target systems. We take our case studies to illustrate this point rather clearly.[22]

That said, it is reasonable to understand analogy as an important component in many instances of model migration. This point is made particularly clear in the excellent discussion of evolutionary biology models being imported into economics provided by Rice and Smart (2011). Rice and Smart discuss two distinct ways in which analogies with biological evolution have been used to construct models in economics. One type is when similarities between *concepts* used to model two types of systems (biological and economic) are exploited for the purpose of economic modelling. This fits very well with the traditional notion of an analogue model à la Hesse. Rice and Smart, however, also discuss another type of 'analogue modelling' within which the *formal structure* of specific models developed within evolutionary biology is adapted for use in economics. This type of analogue modelling is similar to model migration in that it also involves reinterpretation of the representational function of a model from one domain to another. In the examples

[22]There is, of course, *in some sense*, an analogy between particle collisions and money transfers, as there is between genetic evolution and language evolution. However, appeal to such weak analogies would be to put ourselves in danger of trivialising the concept: after all everything is analogous to everything else, *in some sense*.

considered by Rice and Smart it is, however, still based around structural relationships between the target systems, over and above those between the models. In particular, in the example they consider, the key feature behind the successful analogue modelling is taken (by the modellers) to be that the the biological and socio-economic target systems in question contain elements that are interrelated within a similar structure. It is plausibly only such structural relationship between systems that allow for analogue modelling in this sense. By contrast, the target systems described by a model and its migrant counterpart need not contain elements that are interrelated within a similar structure. Thus, Rice and Smart's framework is too restrictive to encompass model migration as we have defined it.

A further related framework is provided by Knuuttila and Loettgers (2014) in the context of application of the Ising model in both condensed matter systems (in terms of the Sherrington-Kirkpatrick model of spin glasses) and neural systems (in terms of the Hopfield model of associative memory). Drawing upon Humphreys' (2004) notions of computational and theoretical templates they develop the idea of a 'model template' as a multiply applicable conceptual and mathematical tool:

> The notion of a model template aims to capture the intertwinement of a mathematical structure and associated computational tools with theoretical concepts that, taken together, depict a general mechanism that is potentially applicable to any subject or field displaying particular patterns of interaction. (Knuuttila and Loettgers 2014, p.295)

In the case of the Ising model the relevant 'patterns of interaction' relate to general cooperative mechanisms leading to collective phenomena. This constitutes precisely the specification of the structural relationships between the target systems that Rice and Smart seem to have in mind in their dicussions of analogue modelling based around formal structure. We can thus introduce a third species of analogical relationship, grouping together the examples that Rice and Smart, and Knuuttila and Loettgers consider. These are 'structural analogies', due to relevant similarity of 'patterns of interaction' between two systems. This is in keeping with Hesse's distincion between 'material analogies' due to relevant similarity of properties between two systems, and 'formal analogies' when two systems are both 'interpretations of the same formal calculus'.

As already emphasised above, our notion of model migration does not in principle depend upon any substantive analogy between target systems existing. It is a phenomenon built upon historical relationships at the level of the models, rather than analogical relationships at the level of target systems; it is about what modellers think, not directly about how things are in the world. This applies equally to structural analogies as it does to material and formal analogies. Moreover, whilst it is most certainly true that most (if not all) examples of analogue models built upon structural analogies *would* count as examples of model migration, the converse relationship, prima facie, does not hold. For instance, it is not clear that either of our two case studies could plausibly be understood as examples of analogue modelling based upon structural analogy. Any argument to this effect would require a great deal of articulation of a relevant *non-trivial* sense of 'structural relationship' between genes and words, and molecules and people. Moreover, on our view, articulating such a relationship for these particular models would be simply beside the point so far as re-sanctioning is concerned. Whilst structural relationships between target systems may be relevant to the 'context of discovery' of migrant models, they are not, in any general sense, relevant to the 'context of justification'. The next

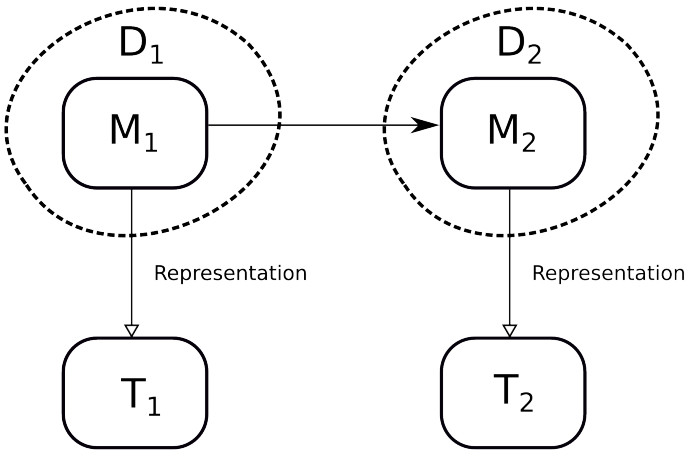

Figure 2: Schematic Representation of Model Migration.

section will make clear why we think it is important to make this distinction between the methodological practice of modelling and the conceptual relations among models.

4.2 Re-Sanctioning

Let us consider the key features of the phenomenon of migration at an abstract level of description and introduce a symbolic representation to aid clarity.[23] In a given disciplinary context, for certain purposes and to a certain degree of desired accuracy, a modelling framework M_1 is adequate for modelling a target system T_1 within a certain domain of conditions D_1. Furthermore, we understand that certain terms within M_1 adequately represent features of T_1 within the domain of conditions D_1. These claims of adequacy are based upon the fact that although such a representation relation may involve idealisations (possibly gross idealisations), justificatory arguments have been provided for the legitimacy of these idealisation within the domain of conditions. In this sense M_1 has been sanctioned. Model migration involves reinterpretation of the model, along with appropriate modification, leading us from M_1 to M_2. M_2 is then a modelling framework operating in a different disciplinary context, that is *claimed to be adequate* for modelling a target system T_2 within a certain domain of conditions D_2. Furthermore, *it is claimed* that certain terms within M_2 adequately represent features of T_2 within the domain of conditions D_2. A schematic digram of the situation is given in Figure 2. The question at dispute is the adequacy of M_2 for modelling (and representing) T_2. And the principal concern is that the justificatory arguments provided for the legitimacy of the idealisations involved in the application of M_1 within D_1, are unconnected to the legitimacy of relevant counterpart idealisations involved in the application of M_2 within D_2.

Let us consider our two case studies once more starting with the kinetic exchange models of gases and wealth distributions. One of the idealisations of the gas model was that all collisions are binary. The justificatory argument for the legitimacy of this idealisation is its approximate truth within the density regime in which the model is being applied. In this regard, the model has been sanctioned. The counterpart idealisations in

[23]Here we are adapting terminology previously used to analyse cases of computer simulation (Winsberg (2009, 2010)) and analogue simulation (Dardashti et al. 2015).

the wealth model is that agential interactions are binary. The original justificatory argument clearly cannot migrate alongside the model since it is not reasonable to talk about 'density regimes' of agents in the relevant modelling context. However, this does not mean that kinetic exchange models of wealth must in principle be taken as illegitimate. Rather, new, context-specific justificatory arguments must be provided to legitimate the counterpart idealisation, and thus support the claim of adequacy of the model within a given domain of conditions. The model must be re-sanctioned. One plausible such argument, that could be given in the new context, but not the old, is the idea of decomposition.[24] Perhaps many-agent economic interactions can be legitimately decomposed into a series of two-agent interactions? If we can think of complicated multi-agent monetary exchanges as concatenations of two-agent interactions then the relevant idealisation can be legitimated, and the model re-sanctioned. Whether or not this particular strategy works, clearly the binary exchanges assumption for the wealth model will require a radically different justification from its gas counterpart. The binary exchange idealisation is not illegitimate in the new modelling context simply because it cannot be justified in the same way as in the old modelling context. This is the essential, and rather straightforward, idea behind re-sanctioning.[25]

An arguably more successful example of re-sanctioning is our second case study: Bayesian phylogeographic models of genetic and language evolution. As discussed above, one of the key idealisations in the genetic model is the use of probabilistic models of nucleotide substitution as representations of the process of genetic mutation. Like in the gas case, clearly the justificatory arguments for the legitimacy of this idealisation in the original disciplinary context will not be applicable in the new disciplinary context. Moreover, there is a clear mismatch between the real process of language evolution, that involves changes in phonology and morphology, and the process represented in the Bayesian phylogeographic model of Bouckaert et al. (2012, 2013), that only involves changes in homology. The particular problem is that the existence of 'borrowings' between languages that may confound any phylogeny based purely upon changes in homology. Thus, the idealisation appears at first hand to be illegitimate. In fact, Bouckaert et al. (2012, 2013), were fully aware of this problem, and as well as pruning their database to remove known instances of borrowings, they did simulations to show that their analysis is reliable provided the levels of borrowings are not too high. Thus, new justificatory arguments were provided to legitimate this particular counterpart idealisation, and re-sanction their migrant model. Importantly, the validity of this re-sanctioning has been accepted even by critically minded historical linguists such as Heggarty.[26] The relevant re-sanctioning has even been used to advocate against reactionary tendencies and towards integration of the new modelling techniques within existing disciplinary practice:

> Bouckaert et al. (2012, 2013) have taken pains to address many of the doubts raised, by thoroughly expanding, revising and correcting the language

[24] In fact, the idea of justifying binary interaction via decomposition is entirely inappropriate to the gas context since the dynamical equation governing gas molecules are generically chaotic for three or more molecules.

[25] As would be expected, the 'analogue species' of migrant model discussed by Rice and Smart would also require re-sanctioning. See in particular Rice and Smart (2011, pp. 671-2). The most vivid example provided is from Rosenberg (1994), whose argument (in our terminology) is that although the idealisation of infinite population sizes can be legitimated in an biological context, the counterpart idealisation, involved in application of the relevant migrant models in economics, is illegitimate.

[26] Contrast in particular, the attitude taken in (Heggarty 2006) with that in (Heggarty 2014).

> database used, and exploring a range of alternative data-sets, phylogenies, models, parameters and constraints, including those advocated by supporters of the Steppe hypothesis. Yet across all of these permutations, the results consistently and strongly favour a homeland in Anatolia instead...Bayesian phylogenetics is unquestionably opening up provocative new perspectives to advance both the Indo-European debate, and the wider endeavour of which it is a part: the search for how best to harness the rich data that lie in the very languages we speak, to tie them in with and complement the genetic and archaeological records of our origins.
>
> Heggarty (2014, pp.576-6)

Such successful re-sanctioning is likely to be in part due to the fact that Bouckaert et al. (2012, 2013) are a multi-disciplinary team including practitioners trained in traditional historical linguistics. Conversely, even the economists who were the most ardent critics of kinetic exchange models of wealth failed to isolate arguably the most crucial re-sanctioning problem: that of binary interactions.[27] Engaged critical analysis of idealisations involved in migrant models requires awareness of modelling practices from both the old and new context. Successful model migration calls for concerted cross-disciplinary efforts in a manner unlike more traditional knowledge transfers that operate within one discipline or between adjacent disciplines. For this reason we believe that migration, and the accompanying re-sanctioning process, call for a specific normative framework. We hope that the following section will go some way towards providing such a framework.

4.3 Norms of Migration

In many senses model migration is a heterogeneous phenomenon and as such the dangers of suggesting general morals for its good practice should be clear. This notwithstanding, we think there are four generally applicable principles that practitioners would do well to heed.

First, and foremost, is the basic message of re-sanctioning. It will, in general, be rare for justificatory arguments for idealising assumptions to migrate alongside the relevant models. This places a clear duty of good practice on scientists to devote resources to isolating and justifying counterpart idealisations. Re-sanctioning can be a subtle business, but without it inferences based upon migrant models are on shaky foundations. Second, conversely, although counterpart idealisations *do* need justification, the mere fact that they are in general unlikely to inherit such justification from the old modelling context does not make them illegitimate in principle. Scientists sceptical of the use of migrant models in the new disciplinary context should thus reserve judgment until after a process of re-sanctioning has been attempted. Third, it is often a difficult task for scientists trained in the old disciplinary context to appreciate the subtle, and sometimes implicit, modelling practices of a new disciplinary context. It is thus important for re-sanctioning to involve, as much as is possible, dialogue between the researchers employing the migrant models and practitioners with training in the new disciplinary context. Fourth, we are not advocating in principle primacy of the existing modelling practices. Sometimes there may be good reasons for the researchers employing the migrant models to ignore

[27] In fairness, the reason for this is probably because it is an assumption that is common in mainstream economics as well.

key elements of standard modelling practice in the new disciplinary context. For one thing, practitioners trained in the new context will often lack awareness of the modelling practices of the old context. This means they may not even fully appreciate what the relevant counterpart idealisations are. Moreover, migration often occurs into disciplines that hitherto lacked sophisticated quantitative machinery, and thus existent methods of evaluating modelling practices may be simply in appropriate. Such considerations do not, however, mitigate the duty of re-sanctioning. They only make it even more subtle.

It is useful to contrast our first two norms of migration with the 'ontological constraint' proposed by Mäki in the context of imperialism. The ontological constraint constitutes a prescription that legitimate scientific imperialism should be based on the pursuit of ontological unification. Our first two norms taken together imply almost the exact opposite with regard to migration. Legitimate model migration is not required to be based upon any form of ontological relationships at the level the target systems. Rather, re-sanctioning may involve entirely new justificatory arguments for the re-interpreted idealising assumptions. It is for precisely this reason that the conflation of cases of migration with cases of imperialism is particularly dangerous and problematic. Applying well reasoned prescriptions for successful imperialism, such as Mäki's ontological constraint, may explicitly conflict with norms for successful migration. Thus, sensitivity to the distinction is important for practitioners not just philosophers. Contrastingly, our third norm and fourth norms are very similar in spirit to Mäki's epistemic and institutional constraints, although more specialised to the particular features of migration as opposed to imperialism. There are clearly general morals for interdisciplinary model transfers that apply across the spectrum of migrant, imperialist and analogical models.

Let us now consider our morals for migration in the context of our two cases studies. We take it to be uncontroversial that econophysicsts generally lack awareness and/or respect for economics modelling practices; and that economists are almost entirely ignorant of the modelling practices of physics. This is a far from ideal situation for both parties. More work in the service of re-sanctioning the models of econophysics would bring both better integration with existing economic work and fuller appreciation of precisely which features of the models would be best to focus de-idealisation strategies upon (for example, how best to improve the 'realism' of the kinetic exchange model by making the agents more sophisticated). That said, the modelling practices involved in much existent economic work are disputed on a number of fronts, and the empirical support that the discipline enjoys might charitably be called sparse. Thus, in line with our fourth moral, we are not advocating assimilation of econophysics into the existing paradigms of economics. Rather we suggest an increase in engagement, and in particular collaboration between the econophysicsts and traditional economists. Our second case study from Bayesian phylogeographic linguistics illustrates the benefits of such an approach particularly well. Just as lack of collaboration makes re-sanctioning more difficult than it should be in the case of econophysics, in Bayesian Phylogeographic Linguistics we see that collaboration between people trained in both disciplines has led to better informed discourse and more effective re-sanctioning.

There are huge potential benefits for the disciplines that encourage successful migration. For example, both historical linguistics and economics lack reliably established quantitative modelling frameworks suited to answering the kind of questions that the relevant migrant models address. Migration of models into these disciplines from the natural sciences in this sense supplies new, and arguably much needed, tools. In linguistics, the role of the Bayesian phylogeographic model of Indo-European languages is that of under-

determination breaking: providing a supplementary analytic tool to help choose between competing hypothesis. In economics the problem of recovering the functional form of wealth distributions is a long outstanding one. The tools of traditional economics are largely unsuccessful in recovering these features. That the econophysics models are being operated using idealisations without adequate justificatory support does not eliminate their superiority in this regard. Rather the onus is upon economists and econophysicsts to combine their efforts towards the re-sanctioning of kinetic exchange models of wealth.[28]

5 Conclusion

The conceptual and rhetorical framework of imperialism is not appropriate to many important examples of inter-disciplinary knowledge transfer. Our two case studies from econophysics and Bayesian phylogeographic linguistics illustrate this point well: the controversy within these cases is nothing to do with scientists trying to subsume economic systems into the realm of physics, or the evolution of languages into evolutionary biology. Rather, we believe that such cases can be understood within the conceptual framework of model migration and re-sanctioning. We believe that there is much valuable work for philosophers of science to do in exploring more cases studies from this perspective. In particular, in the context of model migration, philosophers will find a valuable roles both as *mediators* in disputes between practitioners trained in the old and new modelling contexts and as *advocates* for increased cross-disciplinary work, when and where it is needed.

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[28]For more detailed comparison between economic and econophysics models of inequality see Thébault et al. (2016, §2.1). For highly promising recent commentary and theoretical advances see (Lux 2016) and (Nirei and Aoki 2016) respectively.

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